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Computed tomography measurements of thoracic structures in 26 clinically normal goats

Stefanie Ohlerth [a, *], Mareike Becker-Birck [a], Heinz Augsburger [b], Rahel Jud [c], Mariano Makara [a], Ueli Braun [d]

[a] Section of Diagnostic Imaging, Vetsuisse Faculty, University of Zurich, Winterthurerstrasse 260, 8057 Zurich, Switzerland

[b] Institute of Anatomy, Vetsuisse Faculty, University of Zurich, Winterthurerstrasse 266a, 8057 Zurich, Switzerland

[c] Section of Anesthesiology, Vetsuisse Faculty, University of Zurich, Winterthurerstrasse 260, 8057 Zurich, Switzerland

[d] Department of Farm Animals, Vetsuisse Faculty, University of Zurich, Winterthurerstrasse 260, 8057 Zurich, Switzerland

Running head: CT measurements in the goat thorax

[*]corresponding author. Tel.: +41 6358469, fax: +41 6358940. E-mail-address: sohlerth@vetclinics.uzh.ch

Abstract

The present study was performed to provide computed tomographic (CT) reference values for structures in the thorax of 26 clinically normal Saanen goats. Animals were anesthetized, positioned in sternal recumbency and transverse images with a reconstructed 1.5 mm slice thickness were obtained by use of a 40-slice CT scanner. Absolute and relative measurements of the trachea, heart, cranial vena cava, thoracic aorta, caudal vena cava, right and left principal bronchus, right and left caudal lobar bronchus and the concomitant branch of the right and left pulmonary artery and vein, large caudal mediastinal lymph node and lung density were performed with dedicated software. Minimal to moderate interstitial or bronchopneumonia was incidentally found on CT in 24 animals. In conclusion, CT images obtained in this study can be used as a reference for the evaluation of thoracic diseases in goats.

Key words: computed tomography, multi-slice, reference values, thorax, goat

Introduction

Computed tomography (CT) is a highly reliable, noninvasive technique for the evaluation of thoracic structures and is considered the gold standard to evaluate lung diseases in humans (Collins, 2001). Although CT examinations are rather expensive, the technology has become increasingly available in veterinary medicine. Due to short examination times with multi-slice CT, thoracic scans are easy and rapid to perform in anaesthetized animals. First reports exist on its usefulness in mediastinal and pulmonary diseases in small animals and calves (Au et al., 2006; Henninger, 2003; Johnson et al., 2004; Johnson et al., 2005; Joly et al., 2009; Lubbers et al., 2007). Goats are accepted as a model for biomedical research (Baisden et al., 1999; Fulton and Farris Jr, 1994; Leung et al., 2001; Liu et al., 2008; ten Hallers et al., 2004; ten Hallers et al., 2007) and are presented commonly to our hospital. In selected cases, e.g. pet animals, owners are willing to perform further diagnostic work-up such as CT. The Saanen goat is a popular dairy breed in Switzerland. So far, there are no reports on CT of thoracic diseases in the goat. Therefore, it was the purpose of this study to determine CT reference values for structures of the normal caprine thorax.

Materials and methods

Animals and anesthesia

For the present study, twenty-six dairy goats of the Saanen breed were included. Therefore, animals were all female. The goats originated from two different goat farms in the foothills of the Swiss Alps. Animals were used for milk production only. From spring to fall, they were kept on a mountain pasture. Additionally, they were fed hay and little concentrate. The goats were dewormed regularly. Mean age of the goats was 4.0 years (SD, 1.1 years). Mean body weight was 61.5 kg (SD, 10.4 kg). All goats underwent a clinical examination, echocardiography, complete blood analysis, urinalysis, rumen fluid analysis and parasitological fecal examination. To be included in the study, animals had to be clinically healthy and their echocardiographic examination within normal limits. Serological testing for caprine arthritis and encephalitis had to be negative in all animals. The study was approved by the Animal Ethics Council of the Canton of Zurich.

Each goat was fasted for 24 hours and deprived of water for 2 hours before being sedated with xylazine[*] (0.1 mg/kg, IV); then, anesthesia was induced with ketamine[†] (3 mg/kg, IV) or S-ketamine[‡] (1.5 mg/kg, IV) in 13 animals each and maintained with 2-2.5 % isoflurane[§] delivered in oxygen and air through an endotracheal tube. The first 20 goats were breathing spontaneously during the CT scan, while gentle mechanical hyperventilation was applied before scanning in the remaining six goats to reduce respiration artifacts. All animals received IV lactated Ringer's solution at a rate of 10 ml/kg/h. Heart and respiratory rate, oesophageal body temperature, direct arterial blood pressure measurement via an auricular artery, flow of inhalation gases and oxygen saturation measured by pulse oximetry (SpO_2), were monitored continuously during anaesthesia.

CT examination

The goats were positioned in sternal recumbency and multiple foam blocks were used to obtain a perpendicular position of the thorax relative to the X-ray beam of the gantry. Transverse contiguous slices were obtained from the thoracic inlet to the cranial abdomen with a 40-slice CT

[*] Xylazin, Streuli Pharma AG, Uznach, Switzerland
[†] Narketan 10%, Vetoquinol AG, Ittingen, Switzerland
[‡] Keta-S 6%, Graeub AG, Berne, Switzerland
[§] Forene, Abbott AG, Baar, Switzerland

scanner[**]. Technical settings were 120 KV, 350 mA, 1 s tube rotation, a pitch of 1.2, and 5 mm slice collimation. The data was reconstructed to image series with 1.5 mm slice thickness using a medium-frequency image reconstruction algorithm (soft tissue) and a high-frequency image reconstruction algorithm (bone), respectively. CT images were transferred to a work station and reviewed with dedicated software[††]. Three different windows were applied: a soft tissue window for the mediastinum and the soft tissues of the thoracic wall (window width, 400 Hounsfield units; window level, 40 Hounsfield units), a bone window for the sternum, vertebral spine and rib cage (window width, 3000 Hounsfield units; window level, 300 Hounsfield units) and a lung window for the bronchial tree and the lungs (window width, 1200 Hounsfield units; window level, -600 Hounsfield units).

In the bone window, the height of the thorax was assessed in the transverse plane at 5 levels: between the crista ventralis of the 1st, 2nd, 4th, 6th, 8th thoracic vertebra and the manubrium or the corpus sterni, respectively. Perpendicular to the thoracic height, the width of the thorax was measured between the inner surfaces of both ribs at the level of the 8th thoracic vertebra. The angle between the trachea and the spine was determined in the median plane. The length of the thoracic vertebra, which corresponded to the level of the tracheal bifurcation, was measured along its ventral surface.

In the soft tissue window, the short axis of the heart was measured in the sagittal plane at the level of the atrioventricular valves. Perpendicular to the short axis, the long axis of the heart was measured from the ventral border of the tracheal bifurcation to the cardiac apex. The long and short axis dimensions were added; the sum was transposed onto the vertebral column and recorded as the number of vertebrae (vertebral heart size) beginning with the cranial edge of the

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[**] Somatom Sensation Open, Siemens AG, Medical Solutions, Erlangen, Germany

[††] efilm merge ™2.1, Merge Healthcare, Milwaukee, USA; OsiriX Open Source™ Version 3.2.1, OsiriX Foundation, Geneva, Switzerland

4^{th} thoracic vertebra. In the sagittal plane, the maximal height of the cranial and caudal vena cava and the thoracic aorta was measured; further, the maximal height and length of the large caudal mediastinal lymph node were also assessed.

In the lung window, the maximal height and width of the lumen of the trachea were measured at the level of the thoracic inlet. The cross-sectional area of the lumen of the trachea was measured just cranial to its bifurcation. Just caudal to the tracheal bifurcation, the inner and outer cross-sectional area of the right and left principal bronchus was evaluated. To assess their wall thickness, the difference of outer to inner cross-sectional area was calculated.

Lung density (Hounsfield units) was determined in a defined area of 3 cm^2 at the level of the bronchi lobares caudales in the periphery of the right and left lung parenchyma. At the level of the 6^{th} vertebra, the inner cross-sectional area of the caudal lobar bronchus and the cross-sectional area of the concomitant branch of the pulmonary artery and vein were calculated on the right and left. In the dorsal plane, the angle between the medial walls of both principal bronchi was assessed.

Lung changes were classified according to a system described previously for the assessment of high resolution CT findings in the dog.(Johnson et al., 2004) This classification system represents a modified scheme used for humans.(Collins, 2001) The four major findings and their specific features are 1. linear and reticular opacities including the interface sign, thickened inter- and intralobular septae, peribronchovascular interstitial thickening, parenchymal bands, subpleural interstitial thickening or subpleural lines; 2. small (<1 cm) and large (>1 cm, <3 cm) nodules, masses (> 3 cm); 3. overall increased opacity: ground-glass opacity, crazy paving, calcification or consolidation, and 4. overall decreased opacity: honeycombing, lung cysts, emphysema, bronchiectasis, traction bronchiectasis or mosaic perfusion.

To assess their overall severity and extent, lung changes involving 1-2 regions not larger than 2 cm^2 each were classified minimal. If 3-5 regions ≤ 2 cm^2 or a single region ≤ 10 cm^2 were/was found, changes were classified mild. Moderate changes involved either 6-10 regions ≤ 2 cm^2, 2 regions ≤ 10 cm^2 or up to 50% of a single lung lobe. Severe changes were defined as more than 10 regions ≤ 2 cm^2, more than 2 regions ≤ 10 cm^2 or more than 50% of a single lung lobe of altered lung parenchyma.

Immediately after the CT examination, 12 goats were euthanized and frozen for a comparative atlas of CT and gross anatomy. The remaining 14 goats woke up uneventfully, and were slaughtered within 3-9 days. Subsequently, the cadavers were investigated macroscopically for pathological changes.

Statistical analysis

Distribution of data (continuous variables) was analyzed with box plots, scattergrams and histograms. To assess the association between the different CT measurements, age and body weight, Pearson's correlations were calculated. The paired t-test was used to compare the mean values of the various CT measurements in the right and left hemithorax. The influence of spontaneous breathing versus mechanical hyperventilation was assessed with ANOVA. Commercially available software was used[‡‡]. The level of significance was set at $P < 0.05$.

Results

Although the mean respiratory rate of 24.6 breaths/min (SD, 9.6 breaths/min) was within normal limits (Smith and Sherman, 1994), a mild to moderate increased bronchial sound of the lungs was auscultated in 16 goats. Associated mild spontaneous coughing or nasal discharge was found

[‡‡] StatView 5.0.1, SAS Institute Inc., Cary, NC

in one and two goats, respectively. Mild to moderate anemia and hyperproteinemia was diagnosed in 5 and 7 animals, respectively. On parasitological fecal examination, mixed infections were diagnosed in many goats: *Strongyloides* (9 goats), *Protostrongyloides* (15 goats) and *Dicrocoelium dendriticum* (2 goats).

In Table 1, mean, standard deviation and range of the CT measurements in the thorax of the investigated 26 Saanen goats are presented. Mean cross-sectional area of the wall of the left principal bronchi was significantly higher than on the right ($P = 0.02$). Mean lung density was higher in the right lung parenchyma ($P = 0.04$). Mean cross-sectional area of the left and right branch of the pulmonary vein was significantly higher than that of the branch of the left and right pulmonary artery ($P < 0.01$) (Figure 1).

For the six goats with mechanical hyperventilation, maximal height, width and cross-sectional area of the trachea, and mean inner and outer cross-sectional areas of the right and left principal bronchus were significantly higher than for the spontaneously breathing 20 goats ($P < 0.05$). As expected, certain size measurements, i.e. thoracic inlet height, maximal diameter of the aorta and cardiac width, increased significantly with increasing body weight ($r = 0.4$ to 0.54).

Measurements of the trachea correlated significantly and positively with measurements of both principal and caudal lobar bronchi ($r = 0.39$ to 0.9). Similarly, measurements of the heart correlated significantly and positively with measurements of the aorta and cranial and caudal vena cava ($r = 0.4$ to 0.53).

With the exception of 2 animals, lung changes were diagnosed in 24 goats. Whereas linear and reticular opacities and ground glass opacity were observed in all animals, changes such as consolidation, bronchial pattern or emphysema was only present in 5, 4 and 2 animals, respectively (Figure 2). Small nodules were identified in 17 goats (Figure 3). Irregular pleural thickening was seen in 5 animals (Figure 4). All described changes were seen in the caudal and/or dorsal lung field. Additionally, minimal alveolar changes were found ventrocranial in the lungs in 8 spontaneously breathing and 2 mechanically hyperventilated goats. In summary, a minimal, mild or moderate interstitial pneumonia was suspected in 5, 4 and 4 goats, respectively. In 2, 5 and 4 animals, a minimal, mild or moderate bronchopneumonia was found. In addition, findings suggested mild pleuritis in 5 goats and minimal atelectasis in 10 animals.

At necropsy, lung changes were found in all animals (n=14). Macroscopically, the lung parenchyma appeared focally solid in 6 goats, and in 1 of these animals both cranial lung lobes were atelectatic. In 9 goats, 1-6 nodules were palpated caudodorsal in the lung. Unfortunately, histopathology of the diseased lungs was not performed. In all goats with necropsy findings in the lung, lung changes were also found with CT.

Discussion

The present study was performed to provide CT reference values for structures in the thorax of clinically normal goats. Although only female goats of the same breed were used, thoracic size and shape varied markedly. Further, since various measurements correlated with each other or body weight, the use of size-independent ratios is highly recommended. This may also explain the wide range of angle measurements between the trachea and the spine (10-25^{o}). In the llama, a smaller angle of 10-19^{o} was determined radiographically (Mattoon et al., 2001). In the studied goats, the mean ratio of tracheal height to thoracic height at the thoracic inlet was rather small and similar to the normal brachiocephalic dog (Harvey and Fink, 1982). Therefore, these low values should not misleadingly be interpreted as hypoplasia or tracheal collapse. The mean maximal height of the thoracic aorta and caudal vena cava, the ratio of maximal height of the caudal vena cava to thoracic aorta and the ratio of maximal height of the caudal vena cava to the length of the thoracic vertebra at the level of the tracheal bifurcation were very similar to the normal radiographic values reported in dogs (Buchanan and Bucheler, 1995). In the investigated goats, mean vertebral heart size assessed with CT was lower than in dogs (Buchanan, 2000) but similar to the radiographic mean value reported in llamas (Mattoon et al., 2001).

Although most goats in the present study were clinically healthy, mild to moderate increased bronchial sounds were auscultated in 2/3 of the animals. They occur in disease processes when the bronchial lumen remains open but the surrounding lung tissue transmits sounds better because of being consolidated. This is true of most pneumonias in goats (Smith and Sherman, 1994). At necropsy, nodules were palpated caudodorsal in the periphery of the lungs of 9 goats, and in all goats, parasitic infection with *Protostrongyloides* was diagnosed. Although histology was not available, brood nodules may be therefore assumed in the lung. Parasitic infections are usually subclinical, and only in heavily infested goats they may be pathogenic. As a differential diagnosis, other infectious causes e.g. mycoplasma, paramyxovirus or capripoxvirus, have to be taken into account. Due to the distribution of the nodules, enzootic pneumonia appeared unlikely in the study population because it causes lung consolidation cranioventrally (Smith and Sherman, 1994). Lung disease in the investigated goats was confirmed with CT; in all but 2 goats, minimal to moderate interstitial or bronchopneumonia was diagnosed predominantly in the caudodorsal lung field. In 17 animals, small nodules were identified with CT and suggestive of brood nodules. Only minimal alveolar changes were found ventrocranial in 10 goats, and atelectasis secondary to anesthesia appeared most likely. CT has many advantages in detection of pulmonary changes in comparison to conventional radiography. The cross-sectional image eliminates superimposition of intra- and extrathoracic structures and enables superior evaluation of the lungs. In humans, CT represents the imaging method of choice to investigate lung pathologies (Collins, 2001). Since recently, CT is receiving increasing attention for pulmonary imaging in small animals (Au et al., 2006; Henninger, 2003; Johnson et al., 2004; Johnson et al., 2005; Joly et al., 2009). In the present study, lung changes were classified according to a system described previously for the assessment of high resolution CT findings in the dog (Johnson et al., 2004). This classification system applied very well in the goats of this study. Predominantly, all kinds of linear and reticular opacities as well as ground glass opacity were observed. The caprine lung with its prominent pleura and interlobular septa even shows more anatomic similarities to the human lung than the canine lung (McLaughlin et al., 1961). However, the presence of subclinical respiratory changes in the investigated goats limits the significance of the results of the present study, and measurements may not be considered normal reference values. This is reinforced by the lung density measurements in the present study; values were significantly higher than in the reported normal human or canine lung (Griffin and Primack, 2001; Morandi et al., 2003). On the other hand, clinically unapparent lung changes are rather common in ruminants, and therefore, the results of the present study might just reflect the situation in a normal population.

There was no obvious explanation for the significantly higher values of lung density and cross-sectional area of the wall of the principal bronchus in the left than in the right hemithorax. Animals were always in sternal and never in lateral recumbency and therefore, unilateral hemostasis and hypoventilation can be ruled out. We may hypothesize that the large tracheal bronchus in the right lung leads to an asymmetrical ventilation and therefore, uneven dimensions of the left and right caudal airway structures and different lung density. Due to absent motion artifacts, CT images of the mechanically hyperventilated goats were of higher quality and airway measurements were higher than in spontaneously breathing animals. In the recent literature, a standardized protocol for CT of the lung is recommended and depending on the underlying disease, a scan at end-inspiration with positive pressure breathing and final breath held and sometimes a second expiratory scan are included. The larger size of the pulmonary veins than the arteries may be attributed to the use of vasodilative agents e.g. isoflurane (Takemura et al., 2005).

The similar attenuation of blood, vessels and cardiac tissue, impeded identification of structures of the heart or at the heart base in the present study. CT-angiography, e.g. the use of intravenous iodinated contrast medium in combination with CT, would have markedly improved the depiction of cardiac and vascular structures. The present study was conducted as a part of a larger study describing computed tomography of the normal goat head, thorax and abdomen. Therefore, and because of the withdrawal time, intravenous iodinated contrast medium was only given once, e.g. for the study of the brain, and only in those animals euthanized for anatomy.

In conclusion, the present study presents CT reference values for structures of the normal caprine thorax. Subclinical lung changes were also depicted and described with CT for the first time.

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Figure legend

Figure 1: Transverse CT image (lung window) at the level of the 6^{th} thoracic vertebra. The right and left caudal lobar bronchi (1) are seen. On the left and right, the concomitant branch of the pulmonary vein (2) is larger than the concomitant artery (3) (4: caudal vena cava).

Figure 2 A, B, C: In a goat with mild bronchopneumonia (2A), severe ground glass opacity is seen in one location in the left cranial lung lobe (arrow). Thickened intralobular septae, ground-glass opacity, peribronchovascular interstitial thickening and honeycombing/emphysema are present more in the right than in the left caudal lung lobe in a goat with moderate bronchopneumonia (Figure 2B). Subpleural lines (arrows) are shown in a goat with moderate pleuropneumonia (Figure 2C).

Figure 3: Transverse CT image (lung window) in the caudodorsal lung field: a large nodule (large arrow) is seen on the right and confluent smaller nodules (small arrows) are diagnosed on the left. At necropsy, multiple nodules were palpated caudodorsally in the lung.

Figure 4: Transverse CT image (lung window) at the cardiophrenic angle: the right caudal lung lobe demonstrates a markedly reduced volume, an irregular surface and thickened pleura dorsolaterally (black arrows). Additionally, a parenchymal band is seen (white arrow).

Figure 1

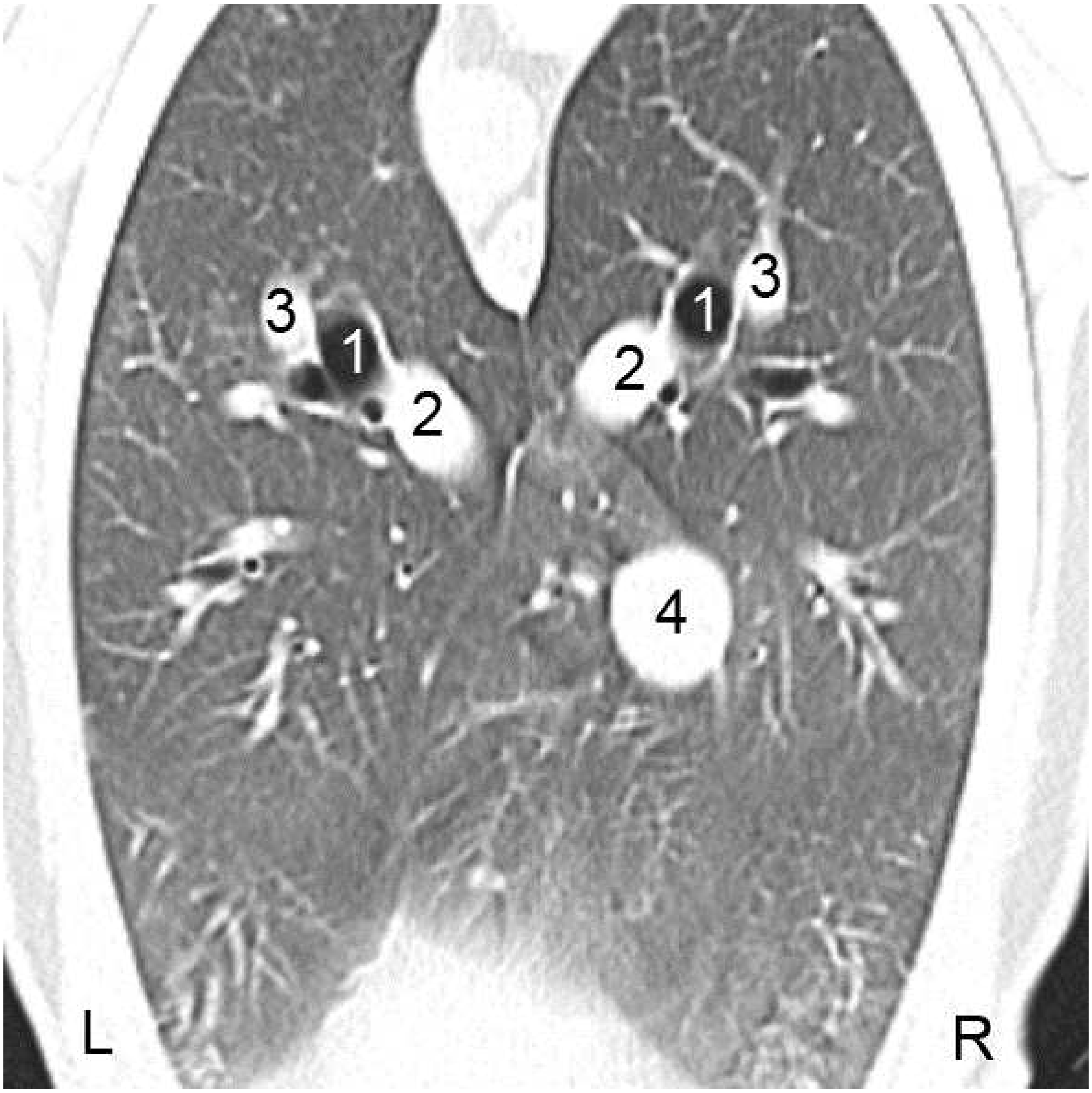


Figure 2A

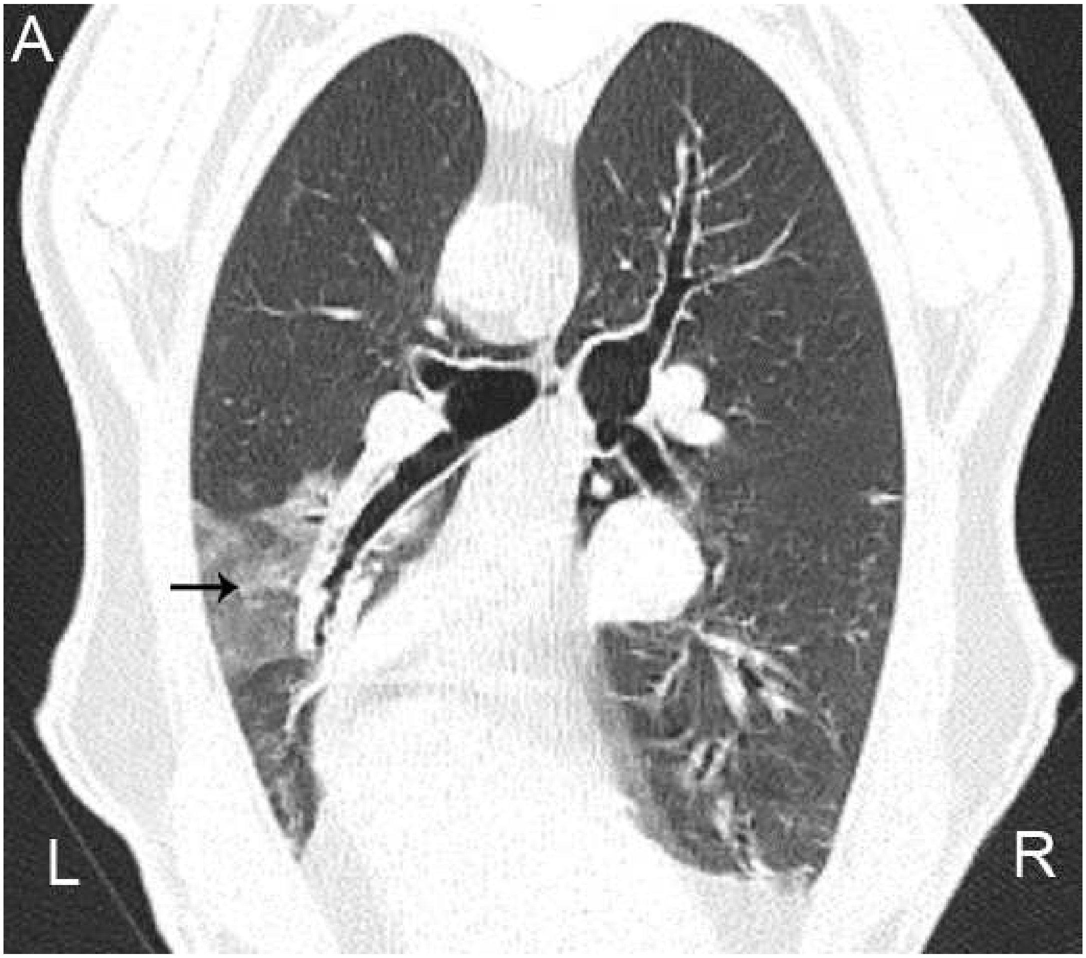
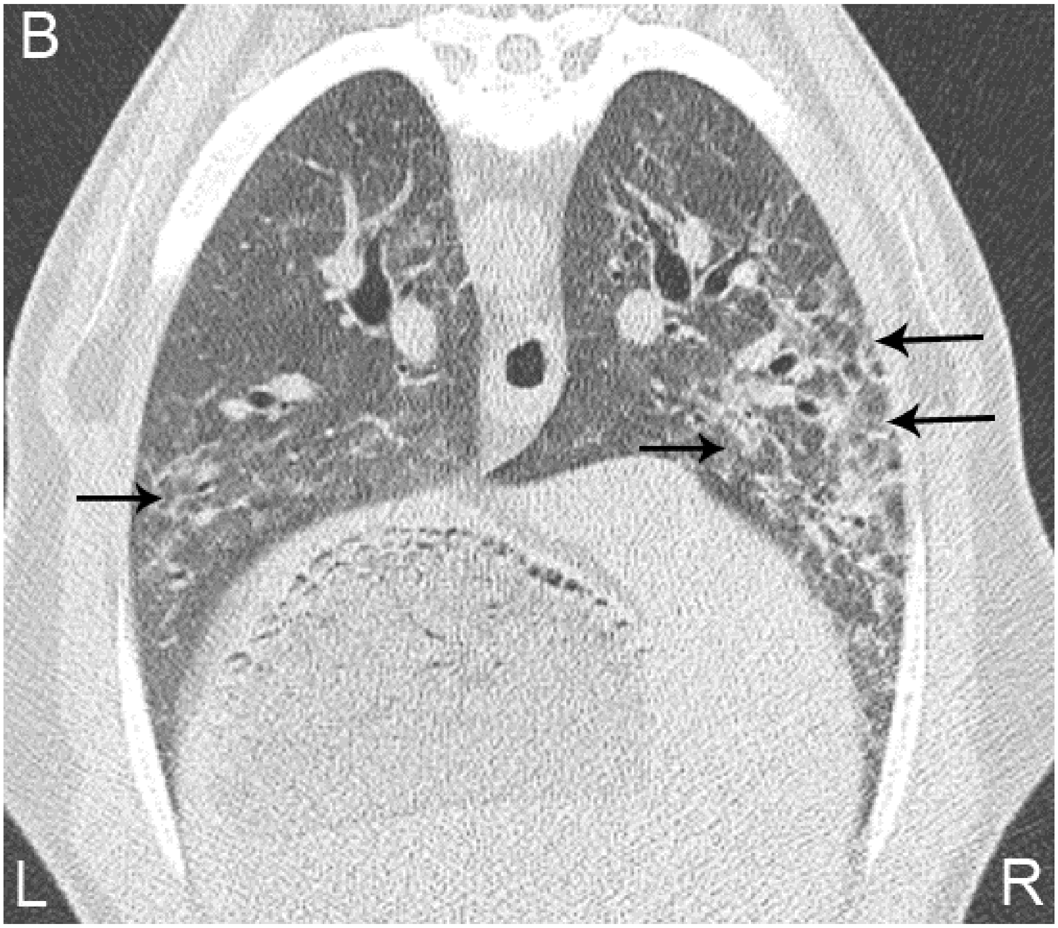


Figure 2B



Fugure 2C

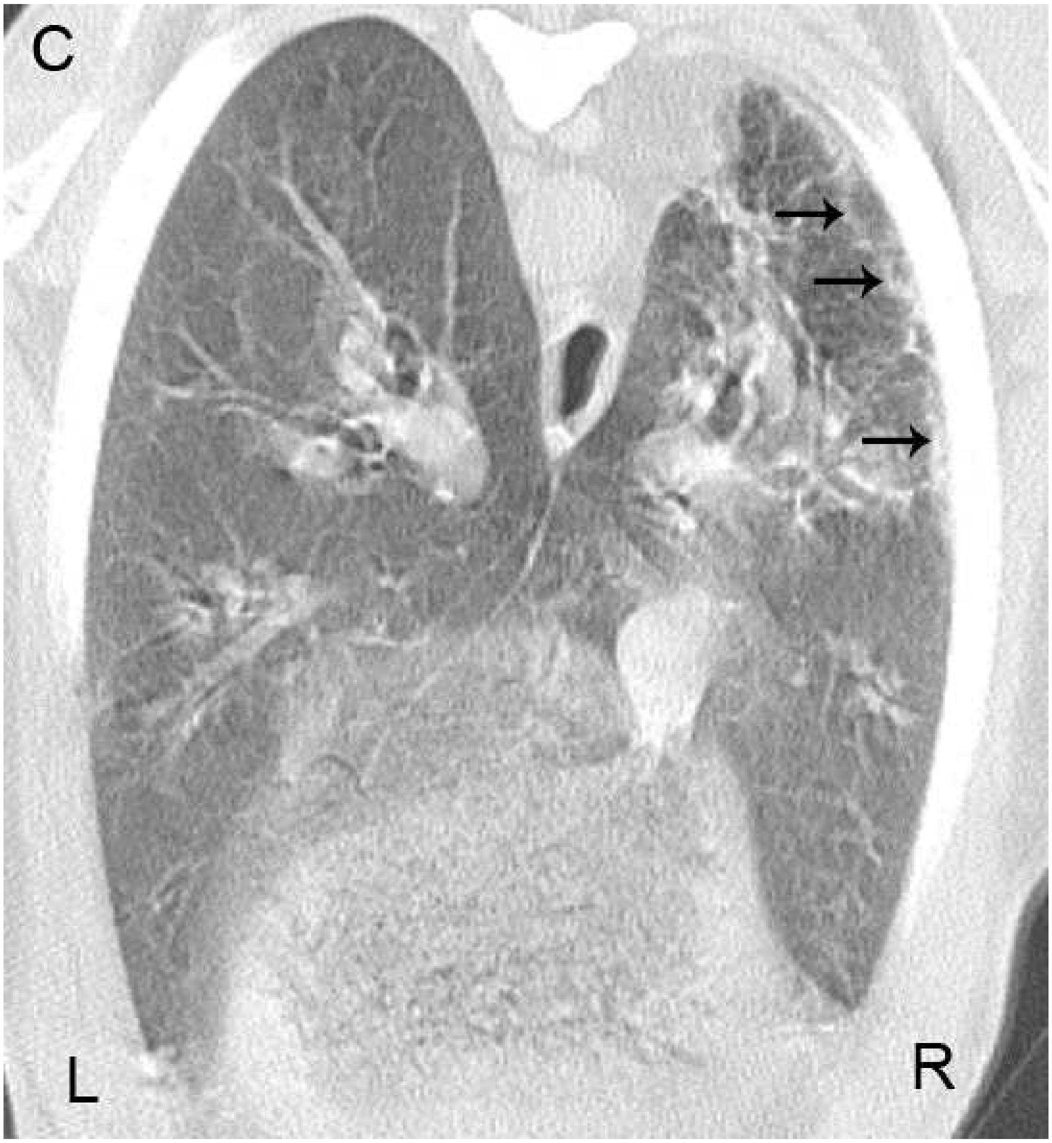


Figure 3

Figure 4